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DEVELOPMENT OF HEAT TRANSFER AND FRICTION FACTOR CORRELATIONS USING DISCRETE DOUBLE ARC REVERSE SHAPED ARTIFICIAL ROUGHNESS UNDERSIDE OF ABSORBER PLATE IN A SOLAR COLLECTOR

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ABSTRACT

The artificial roughness element used an underside of absorber plate is a valuable method to improve heat transfer in a solar collector. In this paper the current investigation was performed using a Discrete double arc reverse shaped roughness element for study of Nusselt Number, Nu & Friction Factor, f properties in solar collector along with the parameters of relative roughness pitch, p/e = 6.67-11.67, relative roughness height, e/D_h = 0.0272, angle of arc, $\alpha = 30^0$-75^0, aspect ratio, W/H = 8 and Reynolds Number, Re = 3000-14000. The rough wall has been heated while the three smooth walls were insulated. The heat transfer and friction factor were compared to the smooth duct under similar conditions of flow and heat limit to determine the thermal hydraulics performance, THP. Statistical Correlations were developed for the Nusselt Number, Nu and Friction Factor, f in terms of geometrical range of roughness element values along with Reynolds Number of flow, Re.

KEYWORDS: Discrete Double Arc Reverse Shaped Roughness Element, Friction Factor, Heat Transfer Improvement, Nusselt Number & Solar Collector

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1. INTRODUCTION

A solar collector is a device used to increase the temperature of air flowing through a heater. Because of its compact simplicity, the solar collector is the most widely used collectors. The main application of this system is the heating of spaces, the drying of crops, the drying of agricultural and related products, foods such as vegetables, fruits, peppers, tea leaves, fish, salt and wood condiments. A solar collector is simple in design and requires little maintenance. A traditional solar collector is usually a flat, rectangular passage between two parallel smooth plates. The air to be heated is passed through a rectangular cross section duct under a metal absorber plate with a side of the sun projected to facilitate absorption of solar radiation incident on the absorber plate. The problem of corrosion and leaks is also less serious. Thermal hydraulic performance, THP of a conventional solar collector is generally poor due to low heat transfer coefficient, h across the air and the absorber, which leads to an increase in the temperature of the absorber plate and consequently to a greater thermal loss. The ribs break down the laminar sub layer and create a disturbance to the local wall due to flow separation and reintegration between succeeding ribs. To improve the performance of a traditional solar collector using artificial roughness in the form of repetitive ribs on an absorber plate (4). Many researchers generated artificial roughness in various forms to enhancement of heat transfer coefficient, h with a minimum penalty of pressure drop. The literature declares that the shape of rib elements has a

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strong effect on Nusselt Number, Nu and fluid flow friction factor, f characteristics.

Prasad et al. (28) they were the first to use a small-diameter wire as roughness element in a solar collector. J. C. Han (9) investigated the evolution of heat transfer in rectangular channels with a rib turbocharger for rib angles from 90 ° to 30 °. The major outcomes of the rib angle and aspect ratio on the local heat transfer coefficient, h have been noticed. Prasad et al. (29) a small diameter wire was used as roughness in a solar collector. They investigated the effect of relative roughness height, e/D_h and relative roughness pitch, p/e on heat transfer and friction factor. Bhagoria et al. (3) investigated the properties of heat transfer and friction factor by experimenting on absorber plate using of wedge-shaped integrated ribs. Pawar et al. (27) conducted a pilot investigation of the fluid flow and heat transfer properties of the solar air heater channel characterized by wedge rib groove roughness element. Gupta et al. (7) transverse rib element used in the sun based air heater for an approximate transitional flow system. Verma and Prasad (42) he did a pilot study outdoors using roughness over the transverse wires. Sahu and Bhagoria (31) experimentally investigated of the thermal performance of the transverse broken ribs 90^0 as approximate elements in the absorbent plate of the rectangular air channel. Jaurker et al. (11) researched a rib cross-sectional experiment to increase efficiency. Layek et al. (19) investigated the heat transfer and friction properties of the transverse bevel groove roughness in the recurring groove in the wall of the plate.

Aharwal et al. (1) examined the thermal performance and pumping properties of continuous inclined ribs with space in the collecting duct for heating air. Saini et al.(35) an expanded metal mesh is used as a roughness geometry. They investigated the effect of the relative length of the long-distance network (l / e) and the relative length of the short-distance network (s/e) on heat transfer and friction factor. Karmare and Tikekar (12) experiments carried out to investigate the effect of metal grit rib element attached to the absorption plate on the heat transfer and friction factor of the rectangular channel. Karwa et al. (13) checked the heat transfer and friction factor of rectangular channels with integrated bevelled ribs on the absorber plate. Layek et.al. (19) The achieved effect of chamfering on the heat transfer and friction properties of the sun based air heater that has a roughness absorber plate with a combined turbocharger.

Momein et al. (23) an experimental study was conducted on the V-shaped ribs as artificial roughness attached to the bottom of the wide channel wall. Hans et al. (6) a pilot investigation was conducted to study the effect of multiple V-shape roughness on heat transfer coefficient and friction factor in roughened artificial solar heater channel. The discrete V-down rib is examined experimentally by Singh et al. (38) used a rectangular channel with a hot, rough wall using discrete ribs on the bottom of the absorber plate. Maithani et al. (21) an experimental study was conducted to improve the coefficient of heat transfer using V ribs and symmetrical gaps when using a turbulence inductor. Muluwork et al. (24) compared the thermal performance of the cross-over ribs in the upper and lower V-apex with the corresponding cross-over ribs. The concept of local turbulence and flow acceleration was used to save gap by Kumar et al. (15). Kumar et al. (16) conducted experiments to see the effect of W-shaped broken ribs used on a large rectangular channel wall for heat transfer and friction properties of a solar air heater. Lanjewar et al. (17) heat transfer in a rectangular channel was examined using its repeated ribs in a continuous W pattern, and the W-shaped ribs were tested for the up and down indication of the flow direction.

Saini and Saini. (33) checked the solar collector with industrial roughness in the form of a arc parallel wire. Singh et al. (37) experimentally investigated the effect of multiple curved ribs on heat transfer and fluid flow properties in a rectangular channel. They performed experiments to study the effect of the geometrical parameters of multiple arc manner ribs. Sethi et al. (39) noticed arc formation in the absorbent plate produced a significant net gain in performance due to

improvements in heat transfer at the expense of plenty of friction losses. It occurs due to the formation of vortices in and around the dimples with flow separators. Yadav et al. (43) found that a significant increase in heat transfer can be achieved by providing arc-shaped protrusions as a result of flow penetration and flow separators in multiple plate locations. Gill et al. (8) executed the study of the solar air heater used of a broken arc rib combined with a staggered rib. Experimental research on heat transfer and flow friction has been reported for an artificially roughened solar air heater duct with transverse rib roughness in the form of small diameter wires in a solar air heater duct by Prasad and saini (29). Instead of transverse ribs, a new concept of dimple shaped roughness was first used by Saini et al. (34). Bopche and Tandale (4) impact analysis carried out of Reynolds number, Relative roughness pitch, p/e, Relative roughness height, e/D_h and Arc angle, α on Nusselt Number, Nu and friction factor, f of rectangular channel. Pandey et al. (25) analytical performance has been done by used of multiple arcs with gaps. Sanjay et al. (36) he conducted a pilot investigation to study the effect of heat transfer and frictional properties of the turbulent flow of air passing through the rectangular channel, which is rough by circular protrusions arranged in an angular arc. Lanjewar et al. (18) investigated the effect of orientations of the double arc ribs on the heat transfer and fluid flow to the rectangular cross-section channel and discovered that the direction of the double arc down performed better than the double arc up and single arc ribs. Kumar et al. (16) a pilot solar hot air heater with arc S-shaped ribs was tested. Sahu et al. (32) an investigation has been carried out for thermal-hydraulic performance of the solar air heater used roughness element in arc manner. Bhushan et al. (3) he studied with the roughness of dimples stepped instead of the occasional roughness of the dimples. Sethi et al. (40) he conducted experimental research on the properties of the heat transfer and friction factor of the solar air heater channel that contained dimple elements arranged angularly as roughness elements in the absorbent plate.

Varun et al. (41) range of geometrical parameters have been reported that affect the shape of the rib element, such as the height of rib element, e, pitch, p and arc angle α, etc. These parameters are generally disclosed in terms of dimensions with non-dimensions such as relative roughness height, e / D_h, relative space location, d/w, relative roughness pitch, p/e, Relative gap width, g / e, relative groove position g / p, chamfer angle, v, etc. Many of the roughness geometries studied by previous researchers have been reviewed and reported in the literature. Prasad and Mullick (28), Hans et al.(6), Saini and Saini (33), Bhagoria et al. (2), Mittal et al.(22), Saini & Verma (34), Sethi et al.(40), Singh et al.(37) and Yadav et al.(43) they conducted experimental investigations on the rough surfaces of the ribs and developed correlations with heat transfer and friction factor. These bindings are used to predict the performance of solar air heaters under various conditions of roughness and operating, and will assist in designing the optimal solar collector.

Sachin (30) experimental studied of heat transfer, and friction properties of the sun based air heater channel with M-shaped geometry as roughness elements in absorbent plate. Mittal and Varun (22) conducted a pilot investigation on the thermal hydraulic performance of a solar air heater that has transverse and inclined ribs as industrial roughness elements in the absorption plate. Patnaik et al. (26) a pilot study was conducted to examine the efficiency of the solar air heater channel with transverse and inclined ribs as artificial rib elements underside of an absorbent plate.

2. EXPERIMENTAL PROCEDURE

Sixteen Roughness absorber plates have been tested as detailed in Table 1; each group consisted of 7 runs at different mass flow rate covering the Reynolds number, Re range 3000-14000. The validity test has been examined and tested on a traditional smooth absorber plate under identical flow conditions and general duct geometrical conditions to serve as a basis for correlated the results with Nusselt Number, Nu and Friction Factors, f in the available correlations for

smooth absorber channel in the literature. A fan draws air through the rectangular duct, and the gate valve is used to control the amount of air in the duct. Out of the entire configuration, from the entrance of the test section to the orifice plate, it was heat insulated. The schematic configuration diagram is shown in Figure 1. The upper side of the channel is covered with black insulating material to reduce thermal losses, thus ensuring that all the energy supplied is transferred from the heater to the duct. Two pressure spigots placed with the central axial line of the smooth absorber bottom wall of the test section were used to measure the drop in pressure at 1.36 m in the span of the experimental test section. The calibrated thermocouples wires of copper-constantan are used to measure the average plate temperature, the mean channel fluid temperature and the air temperature inside and outside. A digital thermometer was used to measure the output of thermocouples through a switch. First of all checked System set up components and devices for systematic operation or in working condition. The experiment was performed under steady state conditions to collect data of heat transfer and friction factor. Assumed steady-state condition during experimentation, when the temperature was not changed between intervals of time 10-15 minutes. The steady-state condition reached about 30-50 minutes when changing the operating status. For each rough plate test, seven mass flow rates were used. The data were recorded for each mass flow and then the flow was interchanged before the system reached a stable state. The following criterions was determined:

- Heated absorber plate temperature at succeeding nine points in length wise axial order
- Duct inlet temperature.
- Duct outlet temperature at four points in length wise order
- Pressure drop of the duct through experiment test section
- Orifice meter Pressure drop.

Table 1: Dimension of Roughened Plates

Plate No.	Rib Element Height, e(mm)	Rib Element Pitch, p (mm)	Relative Roughness Pitch, p/e	Angle of arc, α in^0	Relative Roughness height, e/D_h
1.	1.2	8	6.67	30	0.027
2.	1.2	8	6.67	45	0.027
3.	1.2	8	6.67	60	0.027
4.	1.2	8	6.67	75	0.027
5.	1.2	10	8.33	30	0.027
6.	1.2	10	8.33	45	0.027
7.	1.2	10	8.33	60	0.027
8.	1.2	10	8.33	75	0.027
9.	1.2	12	10	30	0.027
10.	1.2	12	10	45	0.027
11.	1.2	12	10	60	0.027
12	1.2	12	10	75	0.027
13.	1.2	14	11.67	30	0.027
14.	1.2	14	11.67	45	0.027
15.	1.2	14	11.67	60	0.027
16.	1.2	14	11.67	75	0.027

3. REDUCTION OF DATA

Experimental test data, like as plate and air temperature (inlet side and outlet side) at various positions of the channel, were recorded in approximately stable conditions with various mass flow rates (Reynolds number, Re) of air. Data obtained

from experiments have been used to calculate the heat transfer rate, Q and Nusselt Number, Nu for air flowing in the duct. To calculate the friction factor, f the pressure drop was measured in the test section.

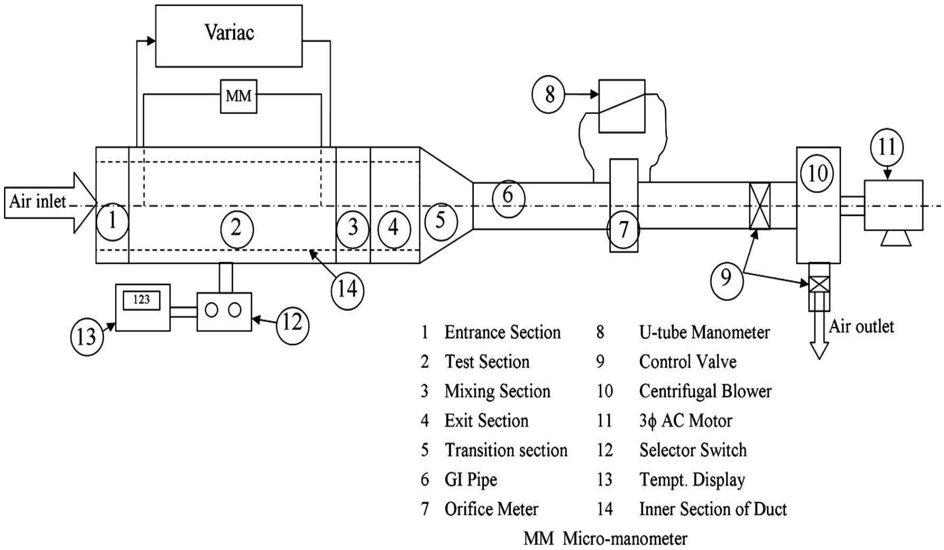


Figure 1: Schematic diagram of Experimental setup.

The experimental setup is validated by conducting experiments for the smooth duct and comparing the obtained results with the standard results achieved by using the equation of Dittus-Boelter and Modified Blasius as validated for the previous studies conducted by Saini et al. (1997), Karwa et al. (1999), Bhagoria et al. (2002), Bhushan and Singh (2011) and many others. The equations used are given below:

Equation of Dittus-Boelter is presented below for Nu_s

$$Nu_s = 0.023 \times Re^{0.8} \times Pr^{0.4} \tag{1}$$

Equation of Modified Blasius is presented below for f_s

$$f_s = 0.085 \times (Re)^{-0.025} \tag{2}$$

The comparison of Nusselt Number, Nu shows that the experimental and calculated values by Dittus- Boelter equation are in good agreement within reasonable limits. Experimental results and Dittus- Boelter results of Nusselt Number values for smooth plate solar collector duct are plotted and shown in figure 2 & 3. From the figure 2, It is clear that the experimental results obtained for the smooth plate solar collector duct are very close to the results calculated by using the Dittus- Boelter equation. The variations in experimental and empirical results are within the acceptable deviations of 8%.

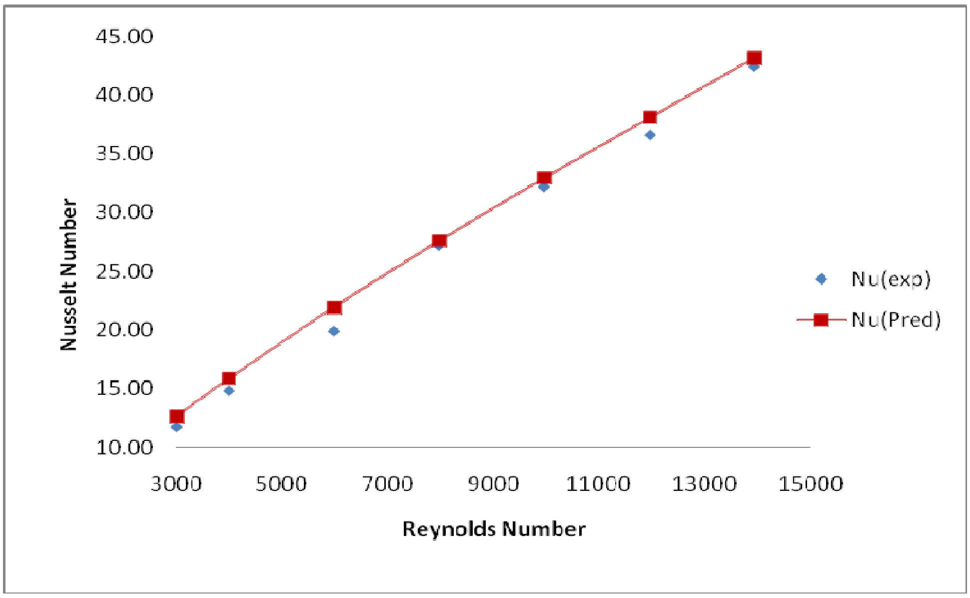


Figure 2: Plot of Exp. and Pred. values of Nu Vs Re for Smooth Absorber Plate.

Friction Factor, f is also calculated by using the modified Blasius equations and the results are correlated along experimental test results. The correlation of predicting along experimental result shown in the figure. It is clear from figure 3 that the experimental results obtained for the smooth plate solar collector duct are very close to the results calculated by using the Modified Blasuius equation. The variations in experimental and empirical results are within the acceptable deviations of 8%.

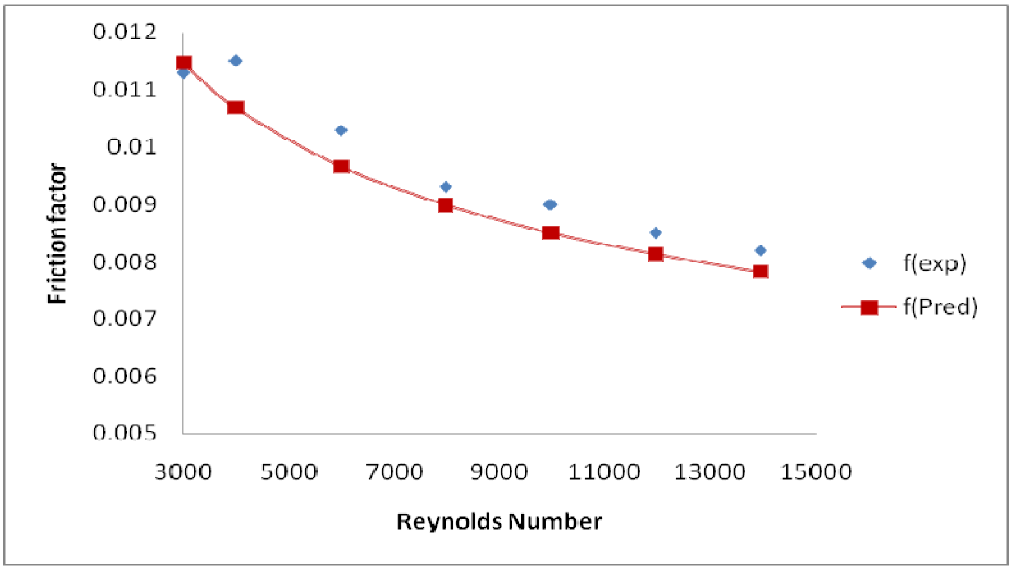
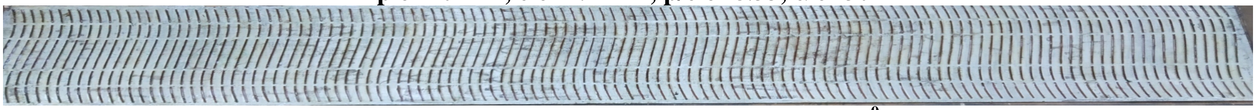


Figure 3: Plot of Exp. and Pred. values of f Vs Re for Smooth absorber Plate

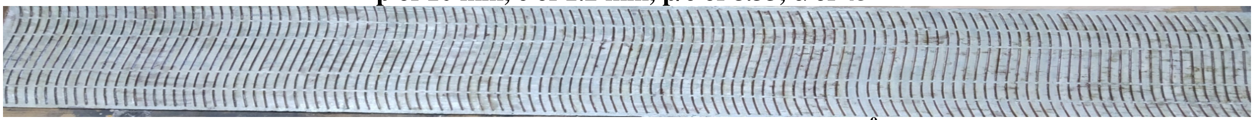
4. GEOMETRY OF ROUGHNESS AND RANGE OF PARAMETERS

Discrete double arc reverse shaped roughness geometry is depicted in the figure, has a pitch, p = 10 mm and $\alpha = 30^0$-75^0. The roughness geometry was created under the absorber plate as shown in Figure 4. Total 16 roughened plates has been fabricated and tested at different pitch (p) and different angle of arc, α and fixed relative roughness height, e/D_h. The range of all investigated parameters is given in Table 2 & 3. The other configurations of different pitches with the different angle of the arc were also used.

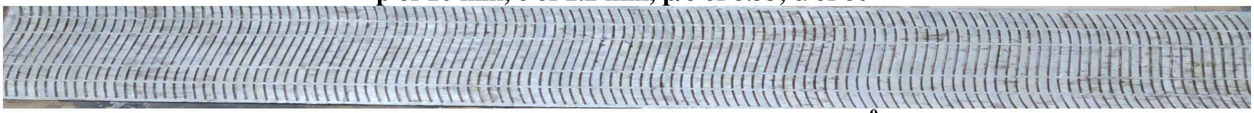
p of 10 mm, e of 1.2 mm, p/e of 8.33, α of 30^0



p of 10 mm, e of 1.2 mm, p/e of 8.33, α of 45^0



p of 10 mm, e of 1.2 mm, p/e of 8.33, α of 60^0



p of 10 mm, e of 1.2 mm, p/e of 8.33, α of 75^0

Figure 4: Roughened Plates Discrete Double Arc Reverse Shaped.

Table 2: Range of Variable Parameters

Sr No.	Parameters	Range
1.	Reynolds Number (Re)	3000-14000
2.	Roughness pitch (p)	8, 10, 12, 14 mm
3.	Relative roughness pitch (p/e)	6.67, 8.33, 10, 11.6
4.	Angle of arc (α)	30^0, 45^0, 60, 75^0
5.	Relative angle of arc (α/60)	0.5, 0.75, 1, 1.5

Table 3: Range of Fixed Parameters

Sr No.	Parameters	Range
1.	Relative roughness height (e/D_h)	0.027
2.	Test Length (L)	1500 mm
3.	Hydraulic Diameter (D_h)	44.44 mm
4.	Aspect Ratio (W/H)	8
5.	Heat flux (I)	1000 W/m^2
6.	Plate Material	G.I. sheet
7.	Thickness of plate	1 mm

5. RESULTS AND DISCUSSIONS

The figure shows the differences of the Nusselt Number and the Friction Factor with the Reynolds number using discrete double arc reverse shaped roughness element with constant values of relative roughness height, e/D_h and aspect ratio, W/H, while the relative roughness pitch, p/e and arc angle, α were in variable form. Results shown that increase of Nusselt Number, Nu with the increment of Reynolds Number, Re and decrement of Friction Factor, f with the increment of Reynolds Number, Re. From the results we can also see that the improvement in the heat transfer of the roughened duct with respect to the smooth duct with increases of Reynolds Numbers.

From the figure 5 found that Nusselt Number, Nu increased w.r.t. increase of Corresponding Reynolds Number, Re for all set of criteria. The highest amount of Nusselt Number, Nu obtained at roughness pitch, p of 10 mm, angle of arc, α of 60^0 & at Reynolds Number, Re of 13935 is 134.63. & The lowest value of Nu obtained at p of 8 mm, α of 45^0 & at Re of 13935 is 97.36.

From the figure 6 found that Friction factor, f decreased w.r.t. increase of Corresponding Reynolds Number, Re for all set of parameters & Vice Versa. The highest value of Friction Factor, f obtained at roughness pitch, p of 10 mm, angle of arc, α of 60^0 & at Reynolds Number, Re of 3010 is 0.0342. & The lowest value of f obtained at p of 8 mm, α of 60^0 & at Re of 13935 is 0.010.

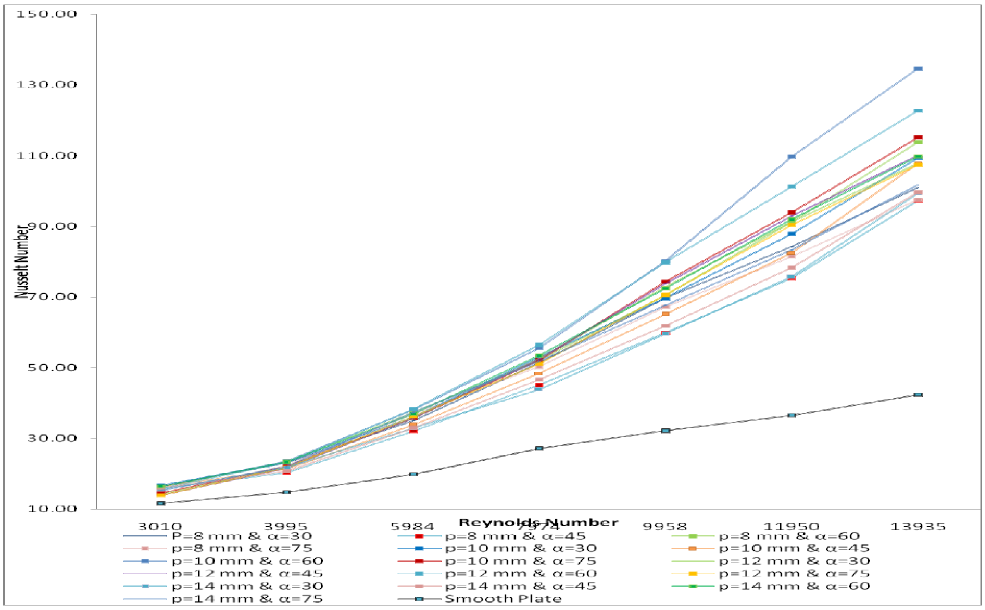


Figure 5: Deviation of Nu with Re for various Roughened Absorber Plates.

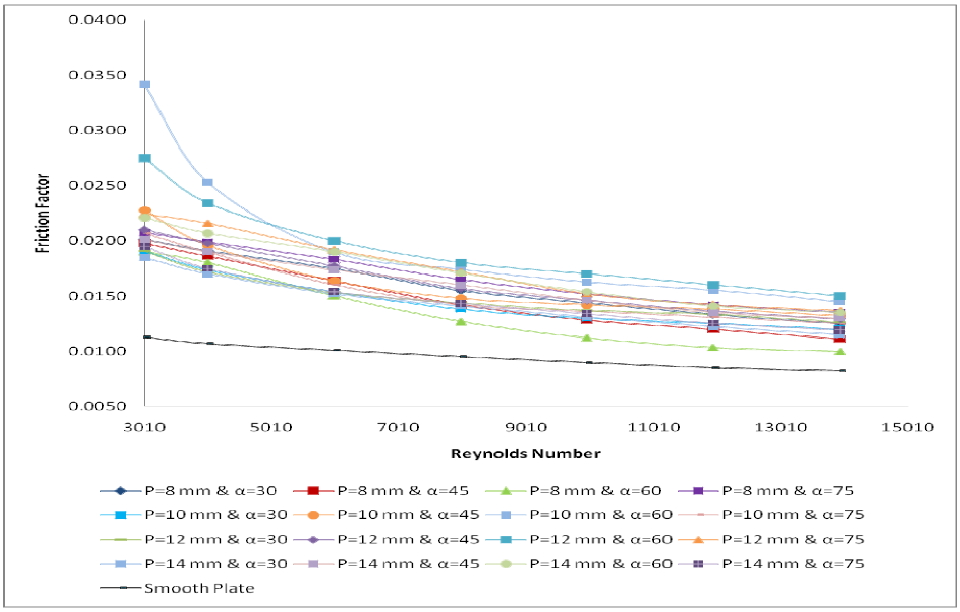


Figure 6: Deviation of f with Re for various Roughened Absorber Plates.

6. DEVLOPMENT OF CORRELATIONS FOR NUSSELT NUMBER AND FRICTION FACTOR

Nusselt numbers, Nu and Friction factor, f are an important function of system and working parameters, which is Reynolds number, Re, relative roughness pitch, p/e and arc angle, α. Therefore, the functional relationships of the Nu and f may be drafted as follows:

$$\mathbf{Nu_r = f_n\ (Re,\ p/e,\ \alpha/60)} \quad (3.1)$$

$$\mathbf{f_r = f_n\ (Re,\ p/e,\ \alpha/60)} \quad (3.2)$$

6.1 Nusselt Number Correlation

Regression analysis based a Statistical correlation was developed of the experimental data obtained through tested work. 16 roughened plate data possessed from the experimental study, the manometer reading through the orifice for calculating mass flow rate of air & corresponding calculate the heat transfer coefficient, h. Nusselt Number, Nu calculated using the heat transfer coefficient values were plotted against the Re and are presented in Figure 7. To fit a straight line through the data point, the regression analysis were carried out, and therefore outcome given below:

$$\mathbf{Nu=A_0Re^{1.261}} \quad (4)$$

The constant A_0 is depends on the criterion of relative roughness pitch, p/e and angle of arc taken α/60. The relative roughness pitch, p/e introduced to observe its influence on Nusselt Number, Nu. The values of $\mathbf{Nu/Re^{1.261}}$ **i.e.** $\mathbf{A_0}$ are presented against relative roughness pitch, p/e as depicted in Figure 8. To fit a straight line through these data point, regression analysis were carried out, and therefore outcome given below:

$$\mathbf{Nu= Re^{1.261}\ [-7*10^{-6}(p/e)^2 + 0.000(p/e) +B_0]} \quad (5)$$

The constant B_0 is a function of other remaining parameter, angle of arc taken α/60. This criterion is incorporated and the values of $\mathbf{[+7*10^{-6}(p/e)^2\ -\ 0.000(p/e)\ +Nu/Re^{1.261}]}$ **i.e.** $\mathbf{B_0}$ are presented against the values of α/60, as depicted in Figure 9. Nusselt Number final term equation is obtained as given below:

$$\mathbf{Nu=Re^{1.261}\ [-7*10^{-6}(p\ /\ e)^2 + 0.000(p\ /e)\ -0.001(\alpha\ /\ 60)^2+0.003(\alpha\ /\ 60)]} \quad (6)$$

The Nusselt Number values evaluated using correlation is correlated with the experimental values as presented in the figure 10. The developed relationship of the Nusselt Number can predict reasonably correct Nusselt Number values within the parameters studied. It was found that the maximum deviation of these cases is ±18%.

The values of constants are $\mathbf{A_0=0.0019}$ **and** $\mathbf{B_0=0.0016}$**.**

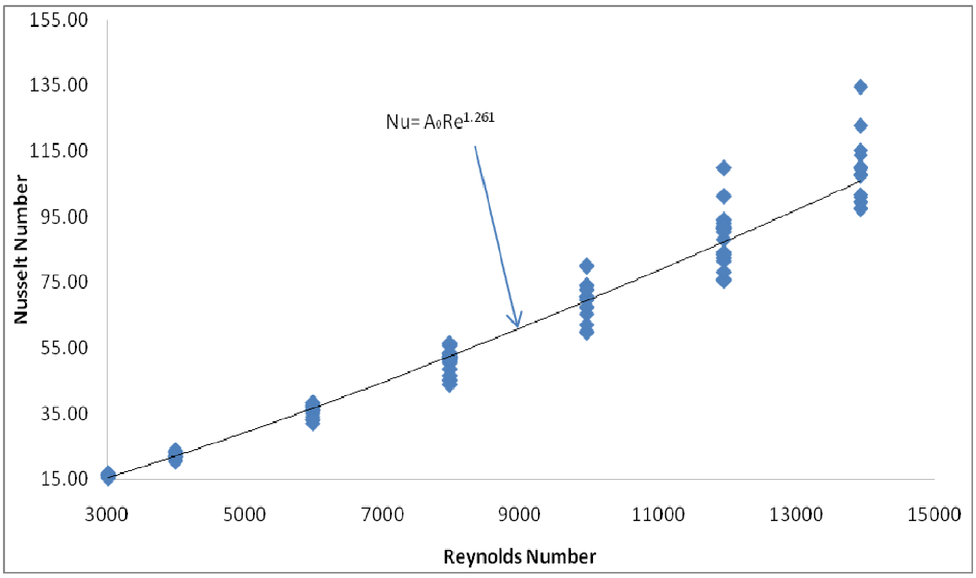


Figure 7: Presentation of Nusselt number Vs Reynolds Number

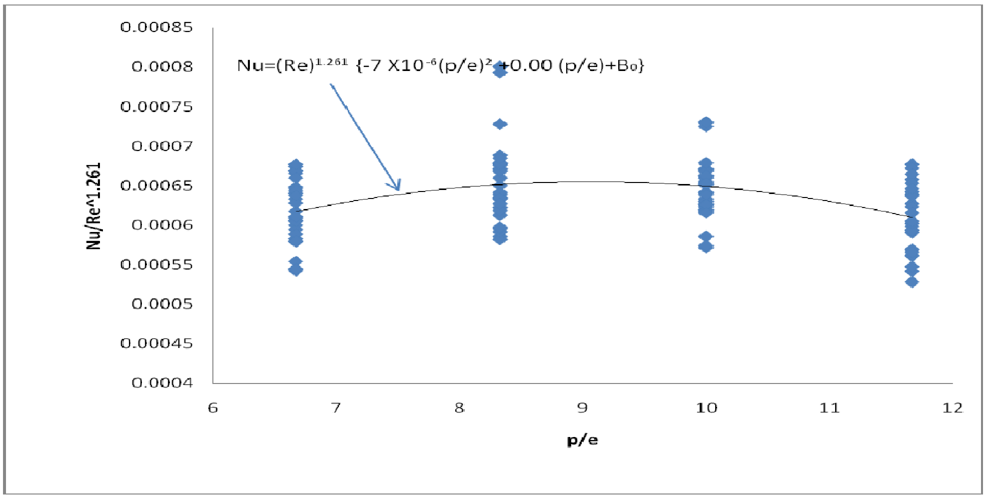


Figure 8: Presentation of $Nu/Re^{1.261}$ Vs p/e

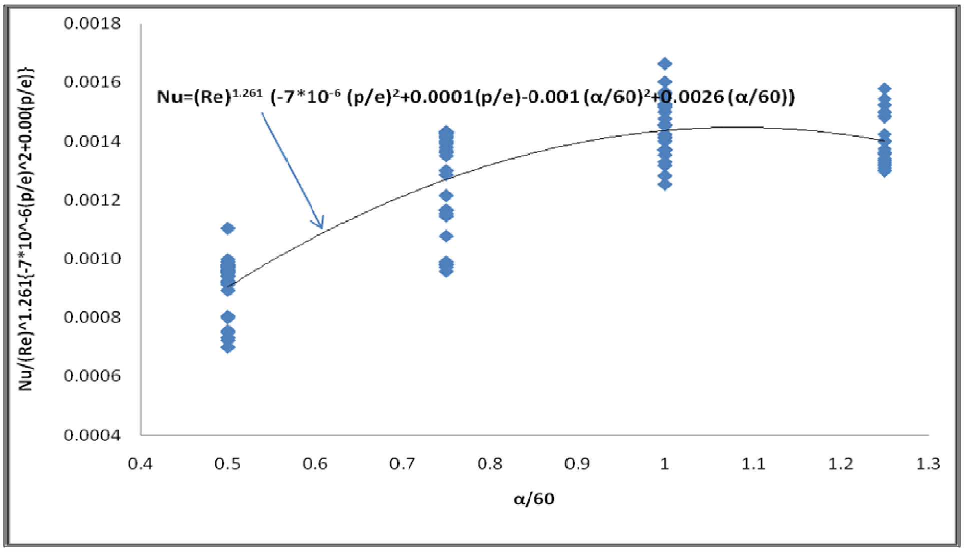


Figure 9: Presentation $7*10^{-6}(p / e)^2$ - $0.000(p / e)$ +$Nu/Re^{1.261}$ Vs α / 60

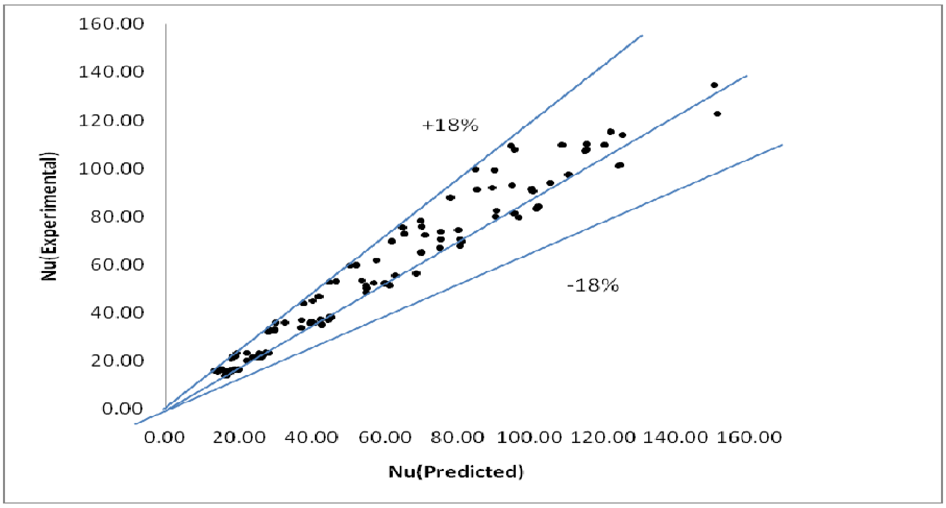


Figure 10: Presentation of Exp. values Vs pred. values of Nu

6.2 Friction Factor Correlation

Friction Factor is an important function of the system and working the criterion of the roughened solar collector duct, i.e. Reynolds Number (Re), relative roughness pitch (p/e) and angle of the arc (α). Therefore, the Friction Factor objective relationships may be presented as follows:

$$\mathbf{fr = f_n\,(Re, p/e, \alpha/60)} \tag{7}$$

To fit a straight line through the data point, applying similar procedure of correlation for Nu, the regression analysis were carried out for Friction Factor, f presented in figure 11. The developed relationship is given here:

$$\mathbf{f = A_1 Re^{-0.34}} \tag{8}$$

The constant A_1 depends on criterion of relative roughness pitch (p/e) and angle of arc taken α/60. The relative roughness pitch (p/e) introduced to observe its influences on Friction factor, f. The values of **$f/Re^{-0.34}$ i.e. A_1** are presented against relative roughness pitch (p/e) as depicted in figure 12. To fit a straight line through the data point, the regression analysis were carried out, and therefore outcome given below:

$$\mathbf{f = Re^{-0.34}[-0.001\,(p / e)^2 + 0.027\,(p / e) + B_1]} \tag{9}$$

The constant B_1 is a function of other remaining parameter, angle of arc taken α/60. This criterion is incorporated and the values of **$f / Re^{-0.34} + 0.001\,(p/e)^2 - 0.027\,(p/e)$ i.e. B_1** are presented against the values angle of arc of α/60 as depicted in figure 13. Friction Factor final term equation is obtained as given below:

$$\mathbf{f = Re^{-0.34}[-0.001(p/e)^2 + 0.027(p/e) - 0.384(\alpha/60)^2 + 0.738(\alpha/60) - 0.138]} \tag{10}$$

The Friction factor values evaluated using correlation is correlated with the experimental values as presented in the figure 14. The developed relationship of the Friction factor can predict reasonably correct Friction factor values within the parameters studied. It was found that the maximum deviation of these cases is ±18%.

The values of constants are A_1 = 0.342 and B_1 = 0.222

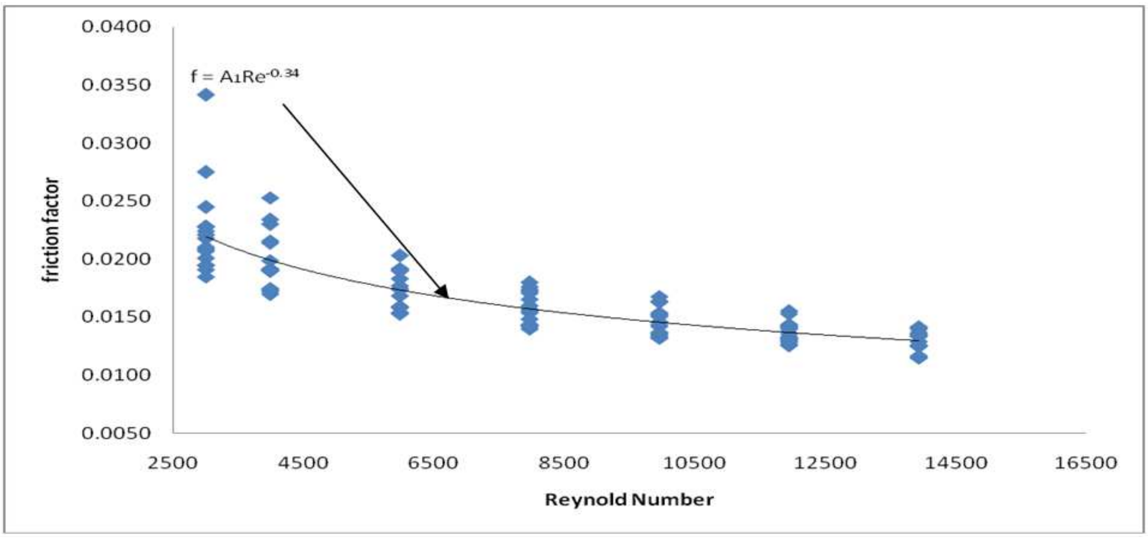


Figure 11: Presentation of f Vs Re

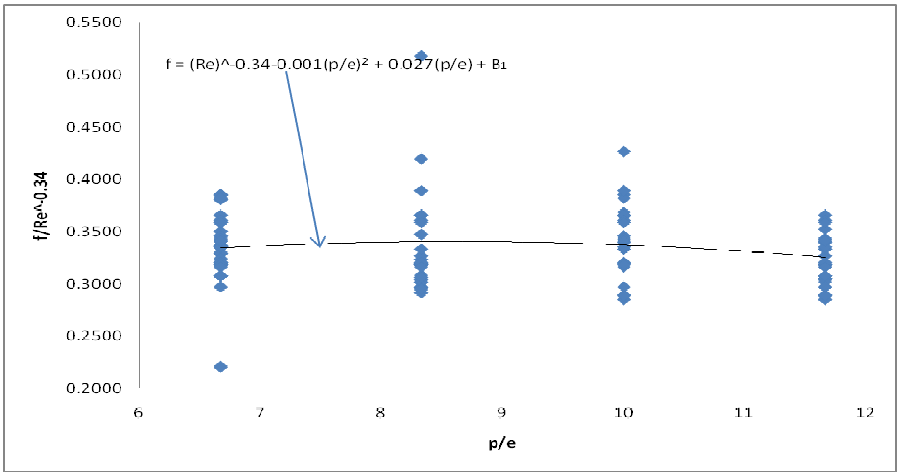


Figure 12: Presentations of f / $Re^{-0.34}$ Vs p / e

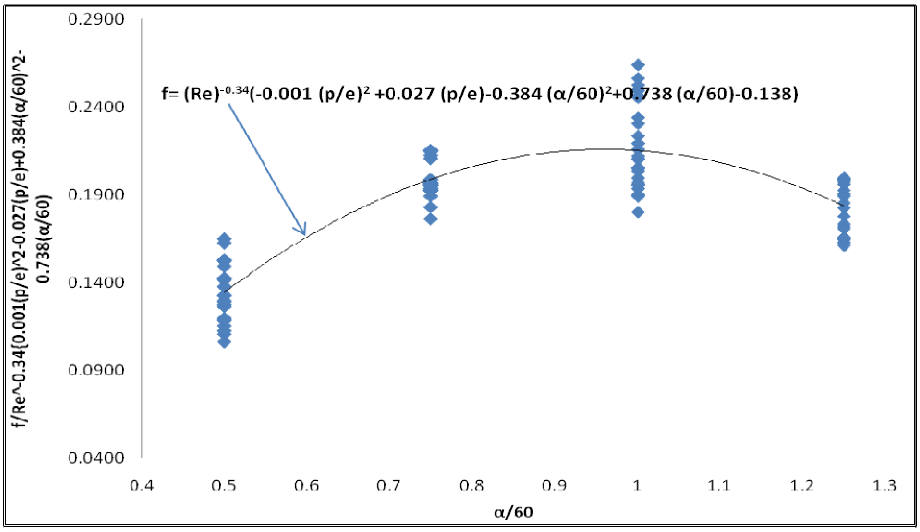


Figure 13: Presentation of f / $Re^{-0.034}$ {0.001 (p /e)^2 -0.027 (p / e)+0.384 (α / 60)^2-0.738 (α / 60)}Vs α / 60

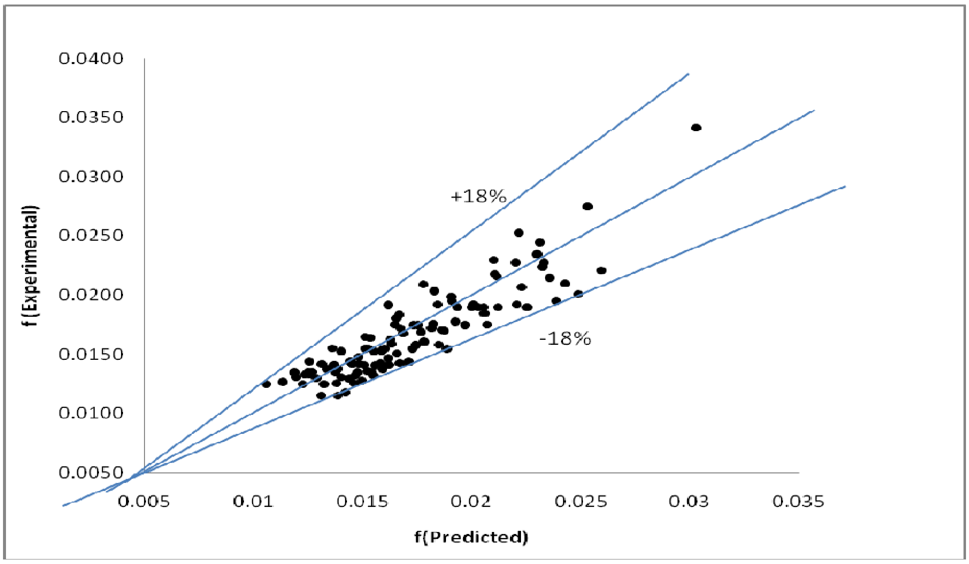


Figure 14: Presentation of Experimental values Vs predicted values of Friction factor

7. CONCLUSIONS

An experimental study of air flow in a rectangular channel with a roughened wall subjecting to uniform heat flow was carried out, with the other three walls being insulated. This criterion corresponds to the flow in the solar collector duct. The influence of the relative degree of coarseness and angle of the arc on Nusselt Number, Nu and Friction Factor, f was studied. The main Conclusions are:

- Presence of discrete arc rib element on one broad wall of a rectangular absorber channel brings about maximum enhancement of 3.17 and 3.02 times in the Nusselt Number and Friction Factor respectively correlated to smooth absorber channel identical working conditions over the range of criteria investigated in Indoor test Experiment.
- The value of Nu improved with an increment of Reynolds Number. For relative roughness pitch, p/e = 8.33, relative roughness height, e/D_h = 0.027 and angle of arc, α= 60^0, highest improvement in Nu was found to be 3.17 times that of smooth absorber duct after experiment.
- The value of Friction Factor, f diminishes with an increment of Re. For relative roughness pitch, p/e = 8.33, relative roughness height, e/D_h = 0.027 and angle of arc, α= 60^0, highest improvement in f was found to be 3.02 times that of smooth absorber duct after experiment.
- Statistical Correlations for Nusselt Number and Friction Factor have been developed as function of relative roughness pitch, p/e, roughness element angle of arc, α and Reynolds number, Re. It has been found that these correlations predict values within the error limits ±18%.
- Observations from the correlations, the influence of Reynolds number on Nu and f are very high from the arc angle to a degree greater than Re in either case.
- Roughened solar collector worked better compared to smooth solar collector. Roughness of Discrete manner has a great influence on heat transfer.

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